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DEPOSITIONAL AND DIAGENETIC MICROFABRIC EVOLUTION OF THE CRETACEOUS OOLITIC IRONSTONE OF ASWAN, EGYPT

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The present work discusses the mode and mechanism of formation of the iron ooids of the Cretaceous oolitic ironstone of east Aswan, Egypt.

Chamositic mudstone, poorly "lean" oolitic, and oolitic sandy ironstones comprise small- scale prograding cycles. The ooids are often found in association with variable proportions of in situ and transported chamositic and hematitic peloids and are classified into : chamositic, chamositic-kaolinitic, kaolinitic, kaolinitic-hematitic and hematitic mineralogical varieties. Genetically, the ooids are differentiated into three main types each displaying its characteristic internal geometry: a) in situ ooids formed by intra-sedimentary accretion below the sediment surface, through re-orientation of the original fine detrital constituents, b) mechanically accreted ooids formed by extra-sedimentary accretion along the sediment/water interface by progressive addition, layer by layer, of original precipitates, and c) ooids formed by intra-and extra-sedimentary accretions . The internal morphology of these ooids reflect a clear variation in the rate of supply of the fine constituents, the strength and direction of currents, the micro-physicochemical conditions and size and shape of the cores of the iron ooids . Chamositization, kaolinization, hematitization, silicification, calcite cementation, compaction and dehydration are the main diagenetic processes that affected the oolitic ironstones .

INTRODUCTION

This work aims to deduce the mode(s) and mechanism(s) of formation of the iron ooids of Aswan oolitic ironstones (Fig. 1). These ironstones terminate short-lived shoaling events expressed by small-scale coarsening-upward sedimentary cycles (El Sharkawi *et al.* 1996a, this volume). The microfacies associations building up these cycles are deduced and presented.

The microfabric and mineralogical composition of the associated ooids in accordance with the hosting prograding cycles are also achieved. Hence, the original microenvironments in which the ooids were formed and/or reworked and redeposited could be concluded. The almost ubiquitous modifications of the ooid morphology and mineralogy by post-depositional pore-fluid activities are also discussed .

The iron ooids of Aswan ironstones are suggested to be formed in sedimentary basin from land-derived weathering products (Abu Zeid, 1965; Bhattacharyya, 1980, 1989; Germann *et al.* 1986, and El Sharkawi *et al.* 1996 a). Volcanic origin was postulated by Tosson (1961) . Schwarz and Germann (1993 a, b) suggested that the iron ooids were formed during lateritization of the hinterland and transported into the marine basin where deposition and diagenesis took place . Bhattacharyya (1980, 1989) classified Aswan oolitic ironstones into "lean" and concentrated ooids . The author identified chamositic, kaolinitic and hematitic ooids within these types .

Bhattacharyya and Kakimoto (1982) related the formation of the concentric oolitic structure of the iron to mechanical accretion of pre-existing detrital particulate mineral grains; namely kaolinite and hydrated iron oxides.

Khedr (1991) subdivided the ooids into shallow-shelf to tidal-flat hematite-kaolinite ooids and lagoonal and lacustrine chamositic ooids .

The present microscopic examination led to the recognition of different petrographic varieties comprising the small-scale shoaling sequence, based on the proportion of the skeletal components relative to the enclosing matrix and the proportion of the different skeletal components relative to each other . The basic nomenclatures for the allochemes (ooids,

peloids and spastoliths) follow the recommended terminology of allochems in ironstones proposed by Young (1989). The observed mineralogical phases are confirmed by XRD analyses of either bulk samples or separated clay samples (<2 μm).

The different mechanism(s) proposed for the formation of the ferruginous ooids of the worldwide oolitic ironstonees can be summarized as follow: 1) replacement of primary calcareous ooids (Kimberley, 1974, 1979& 1980a,b), 2) *in situ* growth as microconcretions or direct precipitation of iron-rich minerals on suspended nuclei (Hemingway, 1974), 3) crystallization from ferruginous gel precursor (Harder, 1978), 4) mechanical accretion of clays or iron-rich mud around scattered nuclei with subsequent transformation to iron-rich phases (Bhattacharyya and Kakimoto, 1982, Van Houten and Buruker, 1984 and El Sharkawi *et al*, 1989), 5) mineralization of calcareous microfossils (Champetiery *et al*, 1987), 6) biological processes, e.g. fungal mats, (Dahanayke and Krumbein, 1986), and 7) direct derivation of iron ooids and pisoids from lateritic soils (Siehl and Thein, 1989; Schwarz and Germann, 1993 a,b and Germann *et al*, 1994).

SHOALING SEQUENCES AND IRONSTONE FORMATION

Aswan oolitic ironstones are confined to the shallow marine succession of the Coniacian-Santonian Timsah Formation cropping out east and south of Aswan city, Eastern Desert, Egypt (Fig. 1).

This formation is built up of four large-scale coarsening- upward sedimentary cycles, representing deposition under a repeated shallowing conditions accompanied acceleration to current and wave activities during a gradual progradation of linear tidal sand/ooid bars on a basal shelf mud (El-Sharkawi *et al.* 1996a, Fig.1, Pl. la). Internally, each cycle consists of smaller ones of medium, and small, scales which represent delimited periods of fluctuation from quiet to agitated condition through the overall shoaling regime. The associated ironstones include non-oolitic, oolitic and storm-generated reworked ironstones (Fig. 1). The oolitic ironstones occur within the middle part of the coarsening-upward cycles and include the following types: poorly "lean" oolitic, true oolitic and oolitic sandy ironstones. These types reflect deposition in agitated conditions along flanks and bar crests

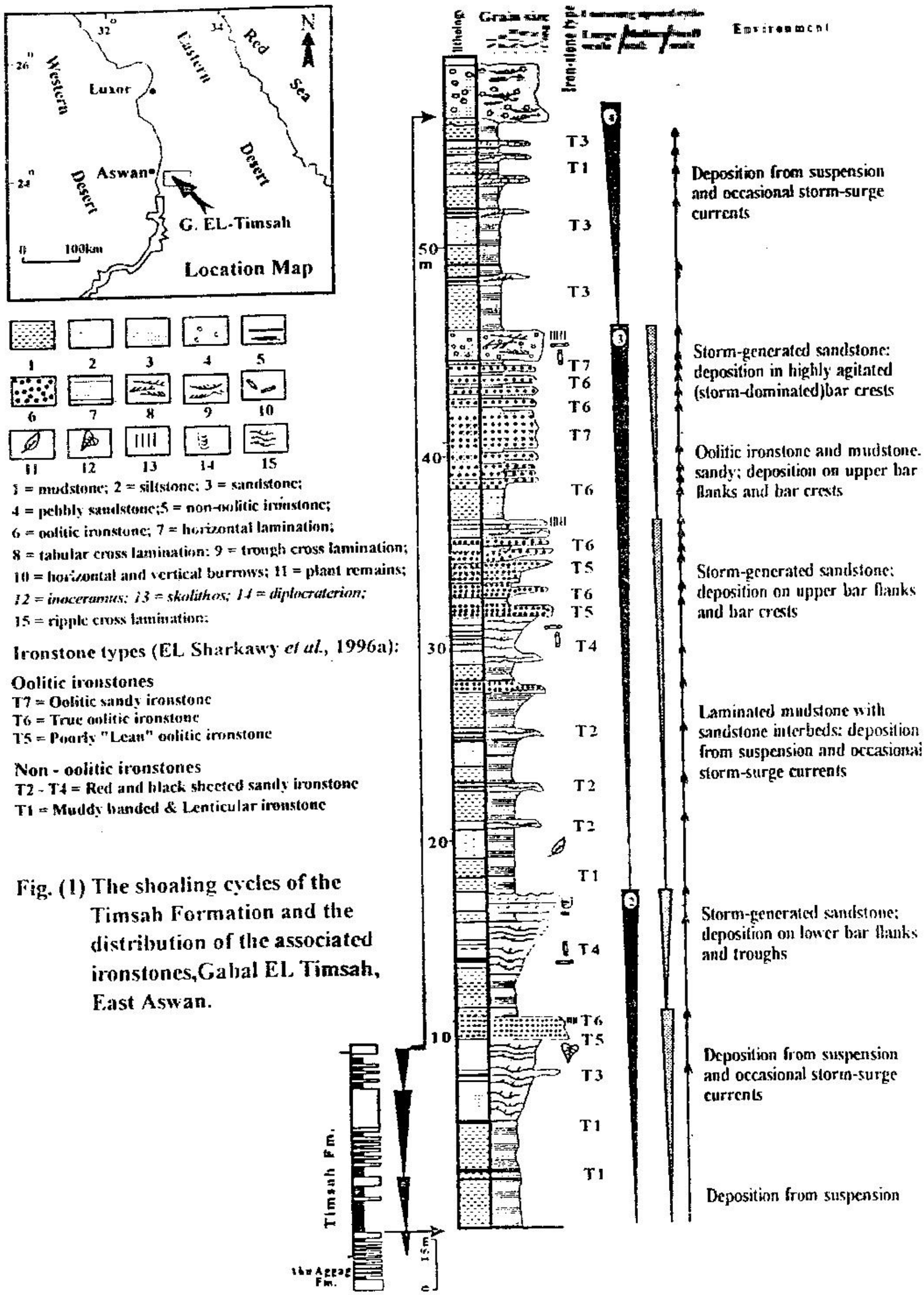


Fig. (1) The shoaling cycles of the Timsah Formation and the distribution of the associated ironstones,Gabal EL Timsah, East Aswan.

during regressive events terminating short-lived small-scale prograding regimes.

PETROGRAPHY OF THE SMALL-SCALE SHOALING CYCLE

Fig. 2 shows the distribution of the different petrographic varieties of ironstones associated with the small-scale coarsening-upward cycles .ferruginous mudstones constitute the basal part of the cycle and grades upward into ooidal wacke-and pack-ironstones. Ooidal grainstones and ooidal sandy grain-ironstone terminate each cycle (Pl. 1b)

Ferruginous Mudstones

These rocks consist of intercalated thin bands and laminae of chamositic-kaolinitic claystone and siltstone. The framework components include silt-sized quartz grains, green chamositic, kaolinitic and hematitic peloids with less frequent mica flakes and superficial ooids (Pl. 1c). These constituents are embedded in a fine-grained matrix of chamositic clays, kaolinite floccules, hematite crystallites and amorphous iron oxyhydroxide. Light colour nodular aggregates of authigenic kaolinite are commonly observed. Towards the overlying wacke-ironstone microfacies, chamositic-kaolinitic ooids are irregularly scattered within these mudstones .

Chamositic-Hematitic Ooidal Wacke-Ironstone

This petrographic lithotype is commonly observed in the uppermost parts of 2). It consists of chamositic-hematitic ooids and spastoliths (< 30%) silt-sized quartz grains and chamositic-hematitic mudstone fragments (20%) floating in a chamositic clayey matrix (Pl. 1d). The ooids are generally rounded to subrounded, moderately to well sorted and range in size from 800 to 1000 μm.

Hematite Ooidal Pack-Ironstone

This lithotype consists mainly of hematitic and kaolinitic-hematitic ooids and spastoliths of grain-supported texture with ferruginous clayey matrix (< 10%) containing less frequent silt-sized quartz grains and mosaic calcite crystals filling the remained pore spaces (Pl. 1e,f) . The ooids, 1000 to 1500 μm in diameter, are generally of rounded, ellipsoidal and disc-like

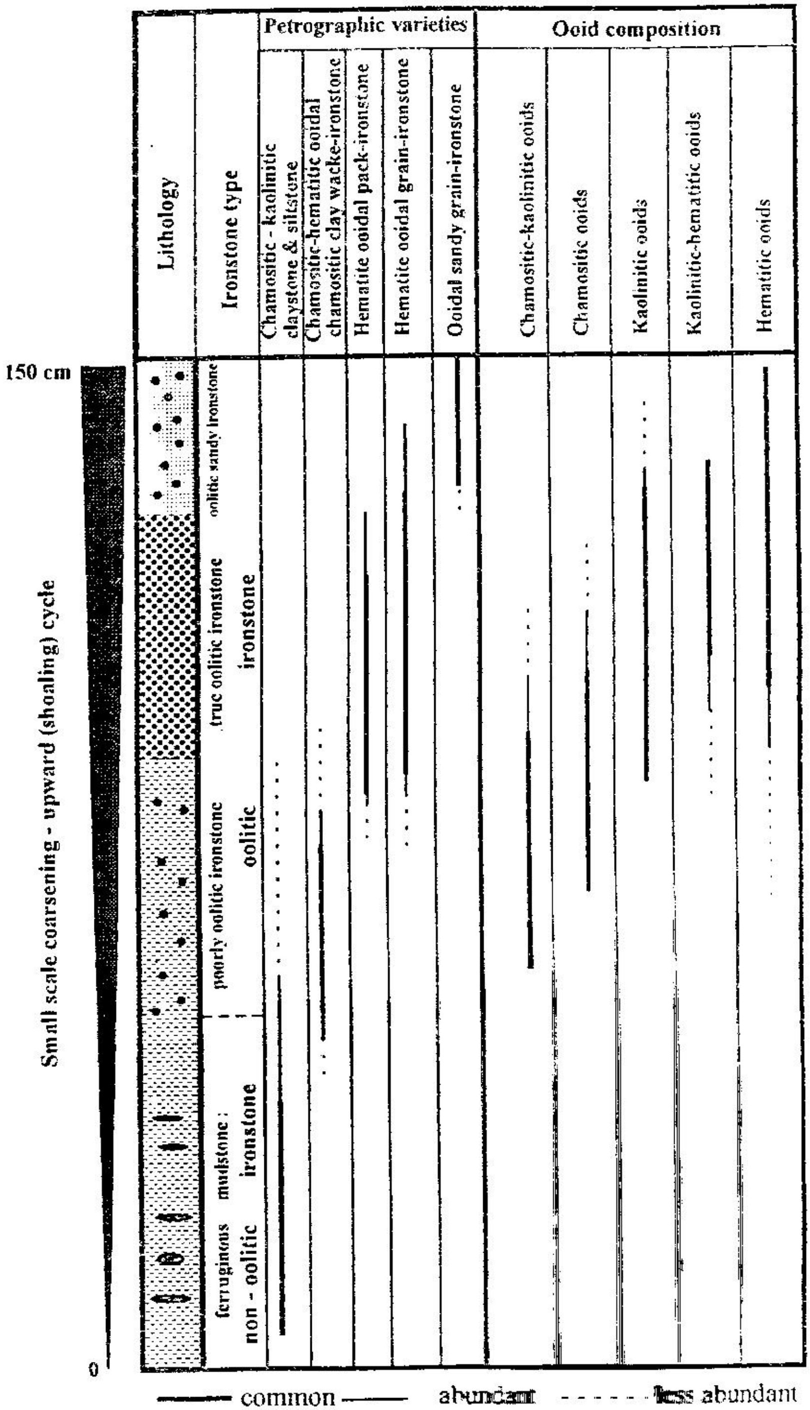


Fig. (2) Petrographic varieties and ooid composition of small - scale shoaling sequence; Aswan oolitic ironstone.

shapes. Internally, these ooids comprise two zones, i.e. an inner cores surrounded by an outer cortices. The cores, 200 to 300 μm in diameter, are massive and composed of chamositic and ferruginous clays containing some silt-sized quartz grains. The cortices, 300 to 600 μm in thickness, consist entirely of concentric and /or eccentric continuous and/or discontinuous laminae of hematite, kaolinite and/or green chamositic clays.

These laminae are oftently dissected and obscured by light euhedral authigenic kaolinite crystals .

Hematite Ooidal Grain-Ironstone

This petrographic lithotype demarcates the tops of the small-scale coarsening-upward cycles, just overlying the aforementioned chamositic-hematitic ooidal green chamositic clays wacke-ironstone (Fig. 2) . It consists mainly of kaolinitic-hematitic and hematitic ooids and spastoliths (> 98%) with less frequent silt-sized quartz grains. These constituents are tightly coalesced together, but they still enclose very small amount of ferruginous clayey materials(Pl. 1g,h). The observed ooids, 600 to 1000 μm in diameter, are generally rounded to subrounded, moderately to well sorted.

The iron-rich ooids consist of rhythmic alternating Laminae of hematite, kaolinite and/or green chamositic clays with less frequent microcrystalline aggregates of quartz. The interstitial matrix consists mainly of ferruginous clays, intermixed with less frequent green chamositic clays, and silt-sized quartz grains. Authigenic growth of secondary kaolinite are frequently observed and led to the destruction of the internal morphology of the ooids .

Ooidal Sandy Grain-Ironstone

It consists mainly of detrital quartz grains of sand size, hematitic ooids and peloids (> 85%) and less abundant muscovite flakes, floating in a fine detrital mixture of crypto-to microcrystalline kaolinite and chamositic clay . Kaolinization of the matrix and hematitization of the chamositic clays are not uncommon .

PLATE 1

a) Field photograph showing the large-scale coarsening-upward cycles of the Timsah Formation (l-4); the fourth cycle is channeled by Um Barmil Formation (U), W. Abu Aggag, east Aswan.

b) Small-scale coarsening-upward sequence of the Timsah Formation. 1=ferruginous mudstone, 2=poorly "lean" oolitic ironstone, 3=true oolitic ironstone.

c) Ovate and disck-like green chamositic clay peloids aligned parallel to stratification, ferruginous mudstone microfacies. (T.S., O.L.).

d) Chamositic-hematitic ooidal green chamositic clay wacke-ironstone showing chamositic kaolinitic and hematitic ooids floating in a green chamositic clay matrix (T.S., O.L.).

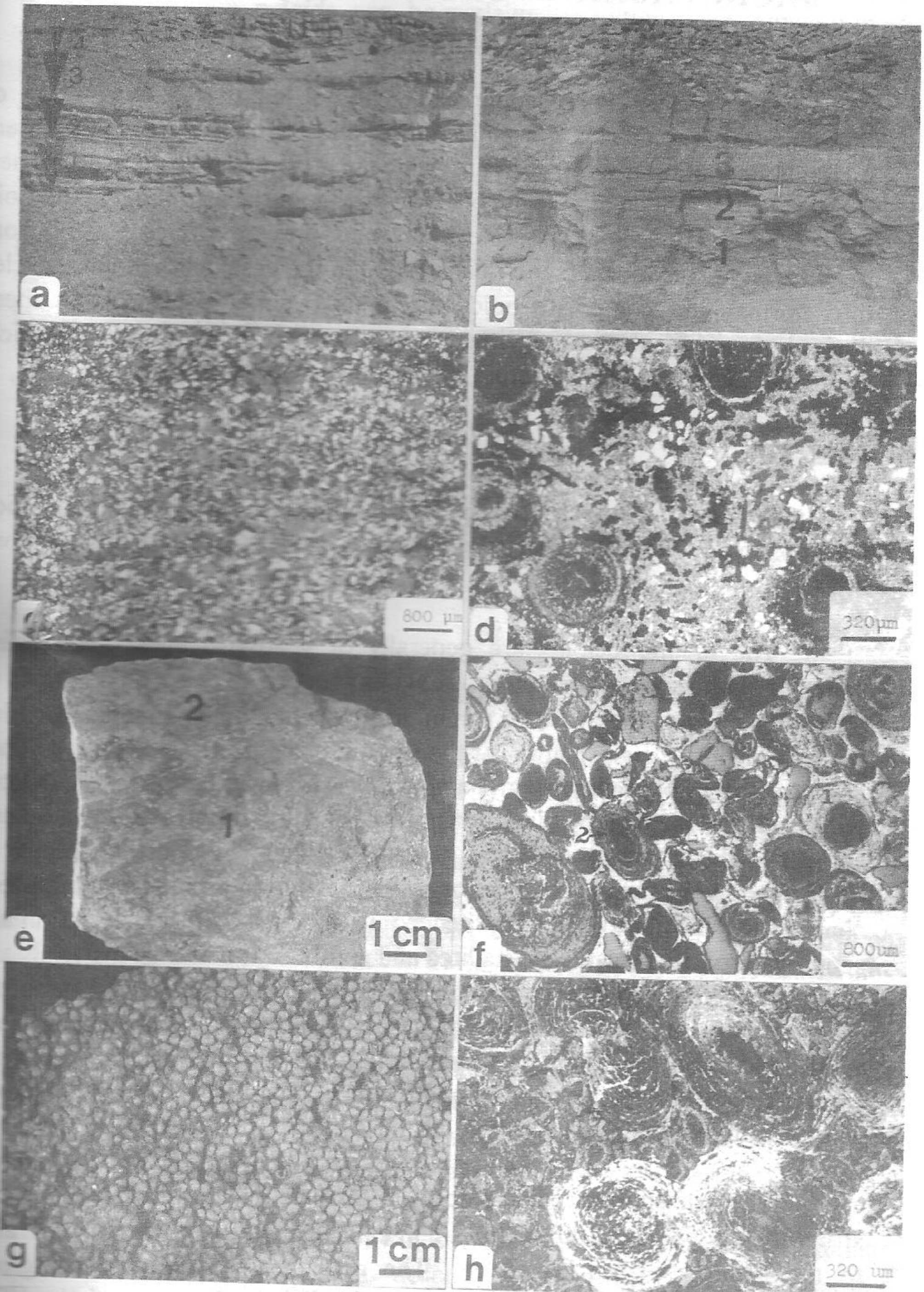
e) Polished slab of the hematite ooidal pack-ironstone (1) grading upward into hematite ooidal grain-ironstone (2).

f) Hematite ooidal pack-ironstone consisting of hematitic (1) and chamositic ooids (2) in hematitic matrix, (P.S., O.L.).

g&h) Handspeciemen (Fig. g) and photomicrograph (Fig. h, P.S., O.L.) for the hematite ooidal grain-ironstone, true oolitic ironstone type.

T.S. = Thin section
P.S. = Polished Section
O.L. = Ordinary Light

Plate 1



MICROFABRIC EVOLUTION AND MECHANISM OF OOID FORMATION (OOLITIZATION)

The present microscopic examinations led to the recognition of different forms of peloids as well as normal and composite ooids of different mineralogical composition, currently showing a diagnostic increasing in their degree of development . There is an obvious upward increasing in the ooid generation within the small-scale coarsening-upward cycles; passing from peloids and proto-ooids (superficial ooids) in the basal parts of these cycles into normal and composite ooids along their upper parts. Within these cycles, there is also an obvious upward variation in the mineralogical composition and internal structure of the studied ooids, (Fig. 2) .

PELOIDS

In situ and transported peloids of different forms and composition are observed within the ferruginous mudstones and oolitic ironstone lithotypes .

The *in situ* peloids are generally of yellowish green and reddish brown colour and commonly present as rounded to subrounded grains of ellipsoidal shape, 200 to 400 μm in diameter, randomly, distributed within the chamositic clayey matrix of the ferruginous mudstones (Pl. 2a) . They are composed of yellowish green chamositic clays and are often associated with and surrounded by dark irregular hematitic micronodules and clots, some of which are cut across by hematite veinlets. Such peloids appear to be formed by diagenetic coagulation and pelletization processes of the green chamositic clay matrix, during penecontemporaneous recrystallization and seggregation of hematite crystallites and amorphous iron-rich materials and formation of hematite micronodules and clots. During these processes, the original clays appear to be compacted and partially to completely pushed aside and coagulated in peloidal bodies. Similar mechanism describing compaction of the matrix mud around the included grains has been described as a deformation texture (Nockolds *et al.*, 1978) .

The transported peloids form a diagnostic ellipsoidal, massive and structureless bodies, 200 to 400 μm in diameter, generally flattened parallel to the bedding planes (Pl. 1c) . The peloids are usually touching one another and oftently highly twisted, loaded and squeezed by The surrounding quartz grains. They form the cores of some ooids or are present

as individuals having the same sizes and shapes of the associated ooids . The formation of such peloids can be explained as follow : 1) accumulation of muddy sediments from fine suspended detrital constituents, mainly detrital kaolinite intermixed with amorphous iron oxyhydroxides and hematite crystallites, 2)the accumulated muddy constituents were firstly chamositized along the sediment-water interface and then reworked and redeposited as green chamositic clay peloids, before or during the oolitization processes in agitated medium. When the reworking processes are well realized, the peloids appear more regular in shape and may have been fairly rounded during transportation. 3) during the agitated condition, the already formed peloids are swept and reworked along the sediment-water interface, then enveloped during mechanical accretion by ooid cortices to form pseudo-ooids or normal ooids .

OOIDS

Three main varieties of ooids are recognized (Fig. 3):(a) ooids formed by inter-sedimentary accretion. b) ooids formed by mechanical (extra-sedimentary) accretion and, c) ooids formed by intra-and extra-sedimentary accretion .

Ooids Formed By Intra-Sedimentary Accretion

Ooids formed by intra-sedimentary accretion are commonly observed within the petrographic lithotypes of the ferruginous mudstones as well as in the fine matrix of the poorly and true oolitic ironstones . They are of different composition including kaolinitic ooids, chamositic ooids and hematitic ooids. They are characterized by : 1) the absence of any true continuous and/or discontinuous laminae and concentric structure which support true mechanical accretion, 2) the cortices of these ooids coat grains of different mineralogical composition which strongly suggest intra-sedimentary accretion (Chauvel and Guerrak, 1989), and 3) The matrix between these ooids is frequently arranged concentrically around the grains and the boundary between the cortical zone (cortice) and the randomly oriented matrix is generally very gradual (Types 1-3, Fig. 3 ; Pl.2b) . This also indicates intra-sedimentary accretion (Chauvel and Guerrak, 1989) .

The observed *in situ* formed ooids can be correlated with similar diagenetic oolites and pisolites described by Carozzi (1960). The author related the formation of these oolitic textures to two main mechanisms: the

first one corresponds to re-arrangement and adjustment of colloidal particles around a point during deposition or in early diagenetic stages . The second mechanism is a differential shrinkage of the area of future oolite or pisolite with respect to the surrounding clay from which it differs in mineral composition, particle size and plasticity. During drying of the clay, concentric cracks are formed outlining areas with the dimension of oolites and pisolites. In these areas, the clays are softer and more plastic than that surrounding the open concentric cracks.

Ooids Formed By Extra-Sedimentary (Mechanical) Accretion

These ooids constitute the main framework components of the oolitic ironstone beds and consist of concentrically laminated cortices surrounding a nucleus. Their external and internal geometric patterns suggest accretion in agitated environment as evidenced by : 1) their internal structure, the cortices of these ooids consist of well defined concentric laminae which indicate a progressive addition of materials, layer by layer, as in typical marine carbonate ooids, 2) the tangential arrangement of the original fine constituents of these ooids (mainly detrital kaolinite floccules and hematite crystallites) which reflect their formation by mechanical accretion processes, and 3) the predominance of juxtaposed quartz grains or smaller ooids within some of these ooids. Based on the external morphology and internal microfabrics of these ooids, they are subdivided into normal, superficial and composite ooids (Fig. 3) .

NORMAL OOIDS

They are rounded, ellipsoidal and oblate in shape and consist of a cortice enclosing a clearly defined nucleus. the cortices consist of delicate concentric laminae varying from 5 µm to less than 1µm in thickness. These laminae are usually coalesced in group forming zones, which are distinguished by colour variation. The normal ooids can be further subdivided into concentric, eccentric and concentric-eccentric types. The terminology used in the description of such varieties of ooids are shown in figure 4 .

In the ***Concentric ooids*** (Types 4-11; Fig. 3), the ooid laminae and zones are distributed concentrically around the nucleus of quartz grains, peloids and rock fragments. They include concentric ooids of rounded shape and internal continuous (Type 4; Fig. 3, Pl. 2c) or discontinuous (Type 5;

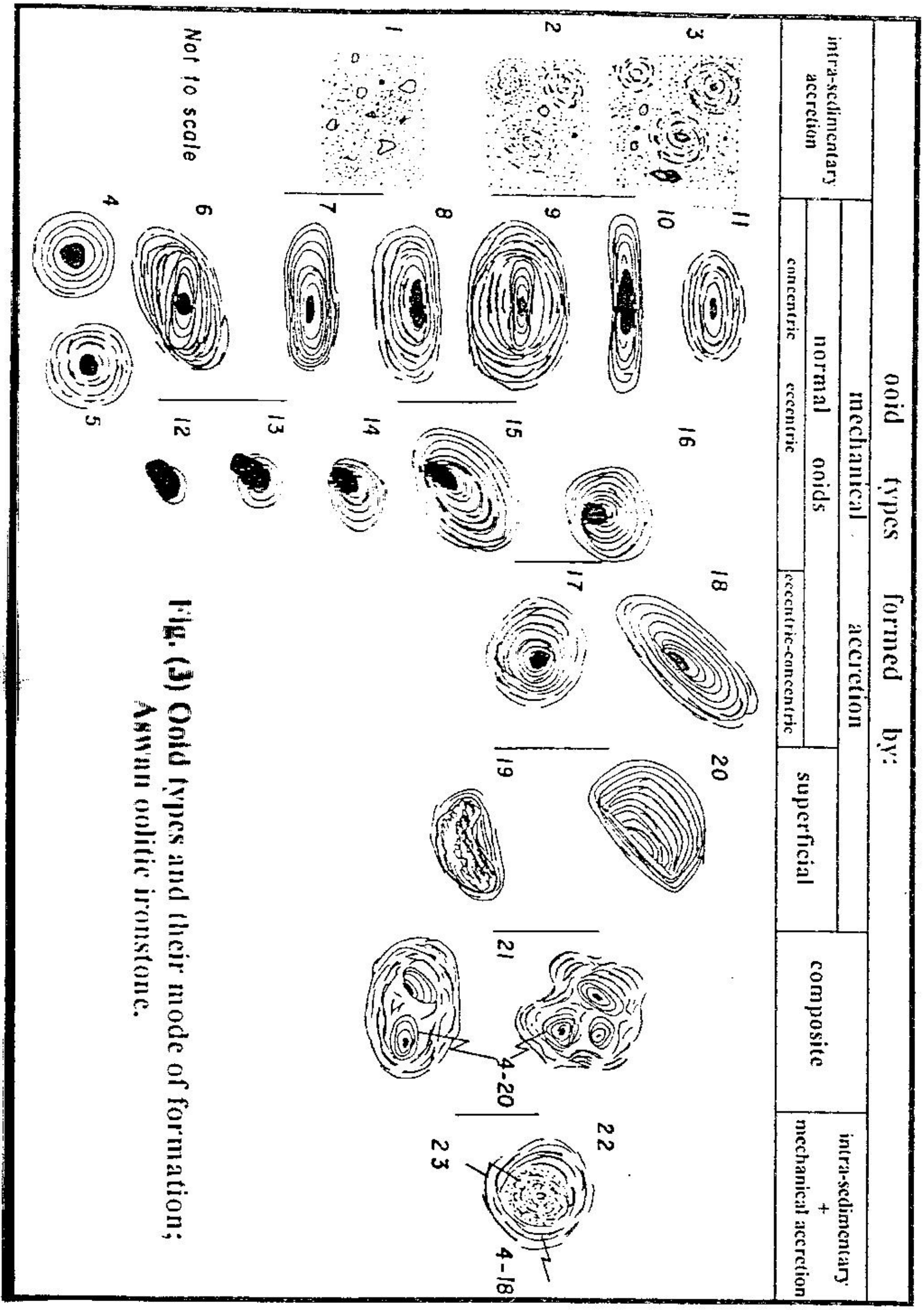


Fig. (3) Ooid types and their mode of formation; Aswan oolitic ironstone.

PLATE 2

a) Rounded to subrounded *in situ* formed peloids. (P.S., O.L.).

b) Intra-sedimentary accreted chamositic ooids, the cortices consist of tangentially arranged green chamositic clay flakes (arrows). T.S., O.L.

c) Concentric rounded chamositic ooid of continuous internal structure (P.S., O.L.)

d) Concentric rounded chamositic ooids of discontinuous internal structure (T.S., O.L.).

e) Concentric symmetrical ellipsoidal chamositic-kaolinitic ooid with equatorial bulge (arrow) in the first stage of accretion and a slight shift in the equatorial plane in the late stage of accretion (T.S., O.L.).

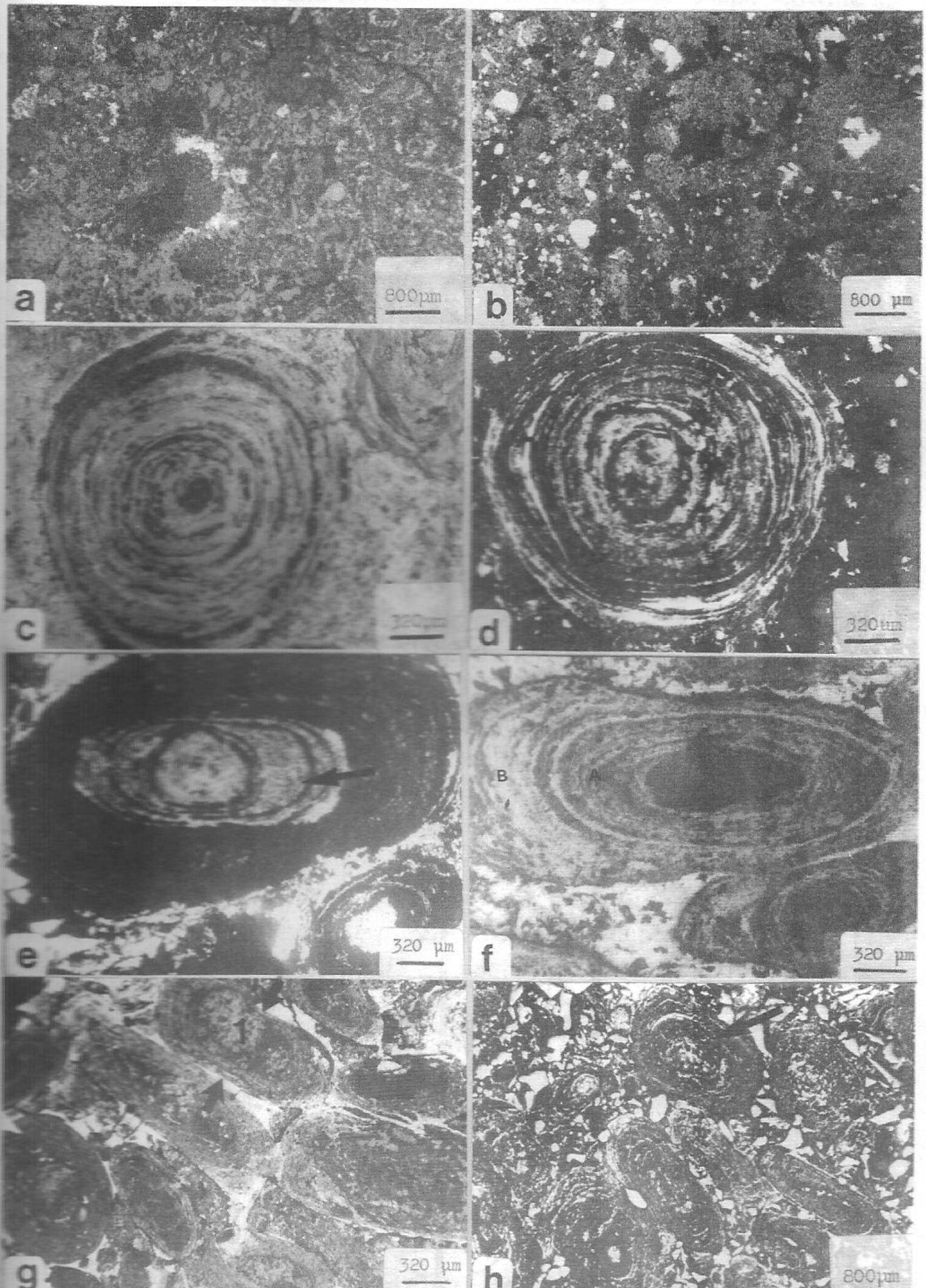
f) Concentric asymmetrical ellipsoidal chamositic ooid with equatorial bulge on both sides in the first stage of accretion (A) and one side bulge in the later zones (B), P.S., O.L..

g) Concentric symmetrical ellipsoidal chamositic ooid (1) showing heavy polar accretion on one surface only (arrows), P.S., O.L.

h) Concentric symmetrical ellipsoidal chamositic-hematitic ooid (arrow) of predominantly polar to predominantly equatorial accretion (P.S., O.L.)

T.S. = Thin Section
P.S. = Polished Section
O.L. = Ordinary Light

Plate 2


a
800µm
b
800 µm
c
320µm
d
320µm
e
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B
A
f
320 µm
g
320 µm
h
800µm

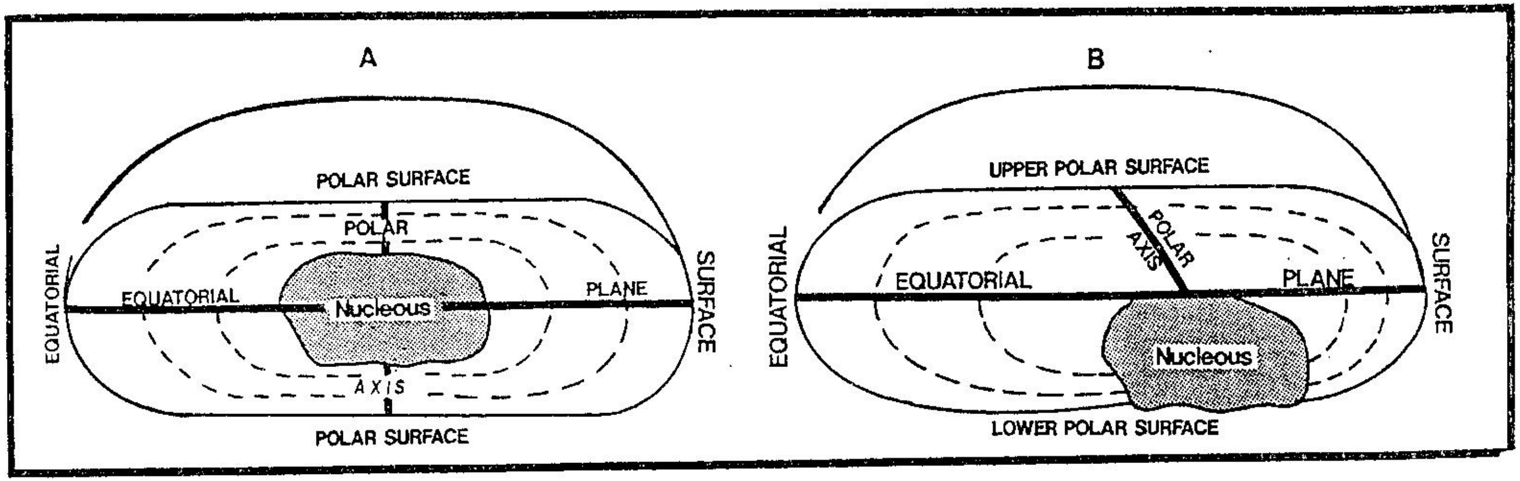


Fig. (4) Terminology for description of oblate ellipsoidal ooliths: A) concentric ooliths, B) eccentric ooliths, (after Knox 1970).

Fig. 3, Pl. 2d) laminae, and concentric ooids of ellipsoidal shape showing a very diagnostic variation in their internal symmetry and also in their outer morphologies.

In type 6 (Fig. 3) there is a general symmetry in the ooid form, but a characteristic equatorial bulge is established in the first ooid zone and a slight shift in the equatorial plane can be recognized in the late stages of development (Pl. 2e). The initial equatorial bulge is due to the discontinuous and relative thickening of the laminae, while slight shift in the orientation of the equatorial plane may represent accretion around a stationary ooid which had come to rest with a slight tilt during its formation. Type 7 (Fig. 3) represents concentric asymmetrical ooids in which equatorial bulge is established in both sides in the first zones of accretion, while in the later zones, one side distribution (bulge or accretion) is present (Pl. 2f).

Types 8 to 11 (Fig. 3) are ellipsoidal symmetrical ooids showing some variations in their thickness and distribution of their internal laminae and zones around their cores. Type 8 shows heavy polar accretion on one surface only (Pl. 2g). The development of polar accretion in the outermost zones is believed to have taken place during stationary phases and not during continuous agitation (Knox, 1970). Type 9 shows change from predominantly polar to predominantly equatorial accretion (Pl. 2h). Polar thickening in the outermost zones suggests that the ooids entered a phase of greatly increased optimum level of accretion before finally ceasing to develop. The thickened polar zones are thought to have been deposited during stationary phases, with intermittent agitation causing the turning over of most ooids. type 10 are ooids showing heavy equatorial accretion relative to polar accretion around a nucleus of lenticular shape (Pl. 3a). Type 11 represents ooids showing polar and equatorial accretion of the same magnitude (Pl. 3a). The development of polar accretion in the outermost zones may lead to an increase in the sphericity of the ellipsoidal ooids.

The concentric symmetrical ooids indicate continuous mechanical accretion and rolling of free nuclei during periods of continuous agitation. The single axis accretion shown by laminae represents the inhibition to accretion in the other axis during any phase of stationary accretion (Knox, 1970). A relatively long periods of immobility must have occurred and unidirectional water movement may have prevailed during the development of the asymmetrical ooids. The overall conditions of concentric ooid formation are therefore envisaged as a quiet water environment in which

PLATE 3

a) Concentric symmetrical ellipsoidal hematitic ooids of polar and equatorial accretion of the same magnitude (arrow) P.S., O.L.

b) Eccentric ooid (arrows) showing the initial stage of its formation, the laminae cover only a small part of the nucleus (P.S., O.L.)

c) Advanced stage in the development of eccentric ooids, the laminae are deposited on the most part of the nucleus (arrows), P.S. O.L.

d) Ultimate stage in the development of eccentric ooids, the exposed surface of the nucleus is completely covered by accreted laminae (arrows), P.S. O.L.

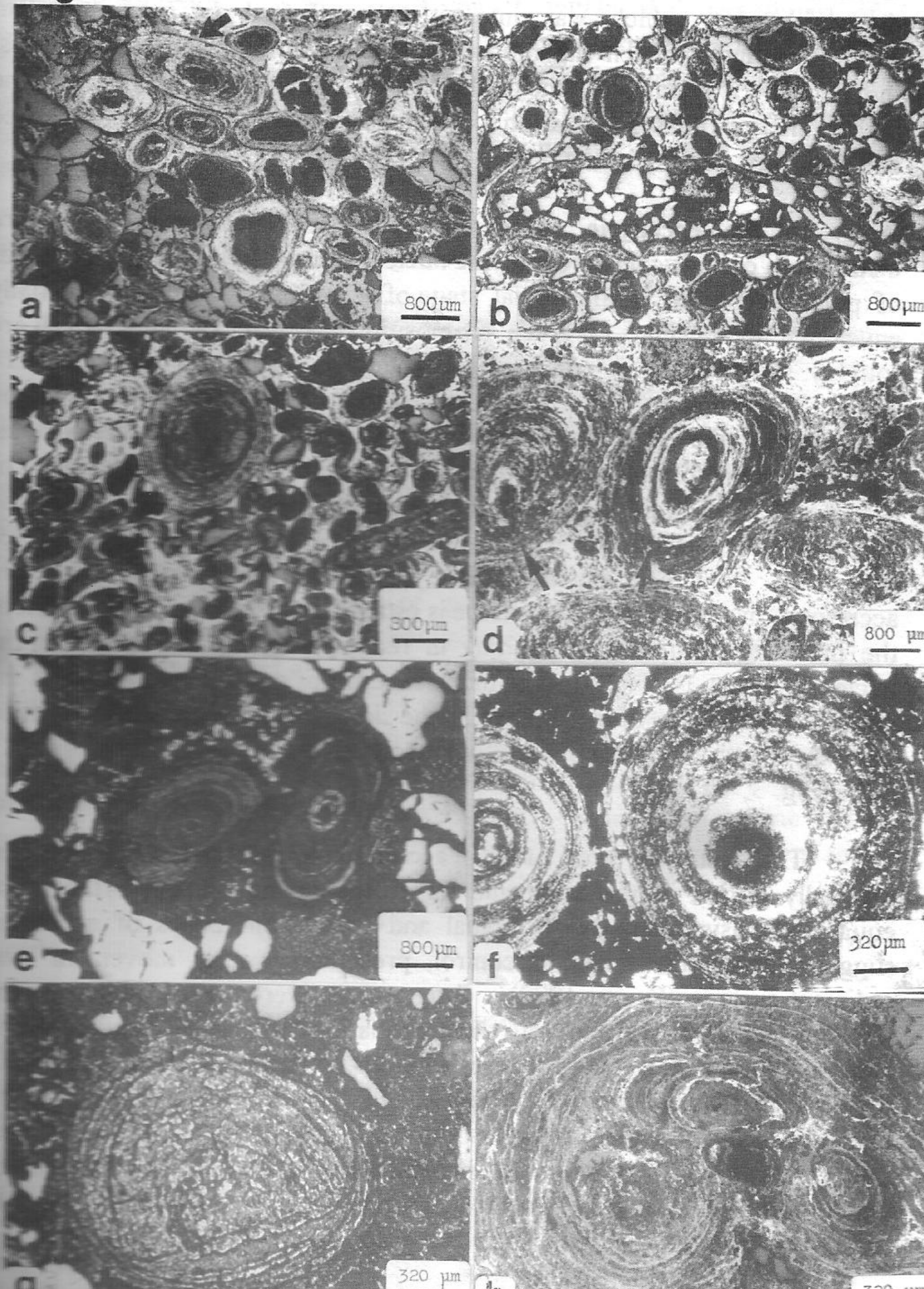
e&f) Eccentric-concentric chamositic ooids consisting of a cores of eccentric ooids surrounded by concentric laminae, P.S., O.L. (Fig. e), T.S., O.L. (Fig. f).

g) Superficial ooid cored by a half-moon ooid fragment (P.S., O.L.) .

h) Composite ooid cored by three simple eccentric ooids (P.S., O.L.) .

T.S. = Thin Section
P.S. = Polished Section
O.L. = Ordinary Light

Plate 3



water movement was for the most part insufficient to cause movement of the ooids, but which was intermittently affected by more turbulant conditions under which the ooids could be turned over and around. Thus, the degree of symmetry in the ooids must be related to the frequency of the higher energy phases in relation to the rate of accretion and also to the size and therefore stability of the ooid.

In the **eccentric ooids** the successive laminae and zones are distributed eccentrically around the nucleus and show a progressive stages of polar accretion. In the initial stage of accretion, the nuclei are partially enveloped by laminae of green chamositic clays and kaolinite, which are roughly semicircular in cross-section and cover a small part of the nuclei (Type 12; Fig.3,. pl. 3b). The surface of initial stage of accretion may be depressed in the direction perpendicular to the elongation of the nucleus, resulting in the formation of an upper polar surface. In an advanced stage of accretion, subsequent laminae are deposited around the junction of the formed upper polar surface with one side of the equatorial surface (Type 13; Fig. 3, Pl. 3c). Subsequent laminae accentuate the equatorial plane and accretion on the upper polar surface is established. Each laminae oversteps the previous laminae and resulting in reducing the exposed surface of the nucleus (Type 14, Fig. 3). The ultimate result of eccentric accretion, is the complete covering of the laminae on the side of initial accretion pass round onto the lower surface until they completely envelope the nucleus (Types 15 & 16, Fig. 3, Pl. 3d).

The restricted area of initial accretion indicates that the nuclei were originally buried in the sediments rather than lying on the surface. The equatorial asymmetry of the initial and subsequent zones of accretion, suggests an unidirectional of control, presumably water movement long sediment-surface (Knox, 1970). Progressive over-step of laminae on the side of initial deposition and the termination of accretion of eccentric laminae can be attributed to the continuous undermining and dislodging of the ooids,. According to Peabody (1947) and Knox (1970), the unidirectional water currents produce circular depressions (current crescents) around obstacles (ooid cores) with a pronounced "moat" on the upper current side as indicated by the downward convexity of the laminae passing-round onto the lower edge of the nucleus.

The **eccentric-concentric** ooids (Types 17 & 18, Fig. 3) show features supporting their formation during more than one stage of

mechanical accretion. These types consist, within their central part, of eccentric ooids which act as a nucleus followed by concentric laminae (Pl. 3e, f). The central eccentric part reflect formation under unidirectional water movement around an obstacle, while the successive concentric laminae indicate subsequent development of concentric laminae around free eccentric ooids under more agitated condition.

Superficial ooids (Types 19 & 20, Fig. 3)

These are ooids with an incomplete or single layers specifically one in which the thickness of the accretionary coating is less than the radius of the nucleus (Beals. 1958). They are cored by chamositic, hematitic and kaolinitic mudstone, siltstone and oolitic ironstone fragments (Types 19, Fig. 3). Less frequent superficial ooids are cored by chamositic half-moon ooid fragments (Type 20, Fig. 3, Pl. 3g). The thickness of the cortices of these ooids is mainly controlled by the shape and external outlines of the nucleus. In the ooids cored by mudstone and siltstone fragments, nuclear concavities are always points of predominant deposition, whereas convexities are points of predominant abrasion or lower depositional rate. The laminae tend toward a more spherical shape as grain growth continue. This is a clear reflection of laminar deposition by mechanical accretion under agitated condition. In the initial stage of accretion in ooids cored by half-moon ooid fragments, the flat-broken surfaces are points of more predominant deposition of concentric laminae completely envelope the half-moon fragments and then tend ultimately to increase the sphericity of the grains.

Composite ooids (Type 21, Fig. 3)

These ooids are usually cored by more than one ooid (Pl. 3h). Their cores are of eccentric type, less frequent concentric ooidal cores are also present. Their cortices vary in diameter from 1000 to 2000 μm and generally consist of concentrically laminated discontinuous green chamositic clays and hematite laminae. The outermost parts of these ooids are partially to completely compressed by the surrounding matrix, which indicate the transportation and redeposition of these ooids in semi-lithified state. These cortices are also thoroughly penetrated by irregular cracks and fractures filled with hematite.

Ooids Formed by Different Modes of Accretion

These ooids show criteria supporting their formation by a combination of both intra-and extra-sedimentary (mechanical) accretion (Type 22, Fig. 3). The central zones of these ooids are formed of intra-sedimentary accreted ooids of type 13 (Fig. 3). These cores are followed outward by mechanically, accreted concentric, continuous or discontinuous, laminae of chamosite, kaolinite and hematite (Pl. 4a), which suggest subsequent accretion and deposition in an agitated environment. Microunconformity surface may separate the central zone from the outer one. These ooids reflect the derivation of central ooidal cores from their original side of formation (below the sediment-water interface) and their reworking and encrustation by younger mechanically accreted laminae above the sediment surface during phases of agitation.

MINERALOGY

The above mentioned mechanically accreted ooids are of chamositic-kaolinitic, chamositic, kaolinitic, kaolinitic-hematitic and hematitic composition. these mineralogical varieties are subdivided and defined according to the predominance (>50 % of ooid cortices by volume) of the appropriate minerals, i.e. kaolinite, green chamositic clays "chamosite" and hematite. The original microfabric and mineralogical composition of the ooids are partially to completely obscured by the impact of post-depositional diagenetic processes including authigenic growths of kaolinite and hematite, compaction and development of shrinkage cracks.

Chamositic-Kaolinitic Ooids

Chamositic-kaolinitic ooids are observed in association with ooids formed by intra-sedimentary accretion within the basal mudstone units and are commonly distributed in the "poorly" oolitic ironstone beds (Fig. 2). Some of these ooids show well defined concentric laminae, others show discontinuous concentric structure (Pl. 2e). The cortices consist of concentrically laminated zones of dark green chamositic clays and light kaolinite. The dark zones, 150 to 200 μm, consist of well defined laminae, 5-10 μm, each one is formed of tangentially arranged flakes of green chamositic clays intermixed with dark brown to black hematite crystallities. the light kaolinitic zones consist of randomly oriented floccules and lath-like tangentially oriented flakes of kaolinite, up to 15 μm in diameter Randomly

distributed hematite crystallites are also observed. In some places, hematite crystallites are touching each other and segregated in certain continuous laminae. In the chamositic-kaolinitic ooids with discontinuous internal structure, it is difficult to follow any concentric laminae around the nucleus, as the laminae pinch out and replace one another. Such an occurrence is very much in favour of a process in which accretion and abrasion phenomena are combined.

Chamositic Ooids

Chamositic ooids are commonly seen in association with the chamositic-kaolinitic ooids, in the lower and middle parts of the poorly oolitic ironstone beds and in the lower parts of the true oolitic ironstone beds (Fig. 2). They show well defined continuous or discontinuous concentric internal structure (Pl. 2c, d, f). The cortices consist of sequential chamositic and hematitic laminae and zones. The laminae, 10 to 15 μm in thickness, are more delicate and fine textured than that observed in the chamositic-kaolinitic ooids (Pl. 4a). Each laminae can be traced for more than 2/3 of the total peripheral area of the ooids, but generally, the hematite laminae are of sharp boundaries and of more persistent extension than the green chamositic clay laminae. The contact between these concentric laminae and the inner cores are indistinct while the contact between the outermost concentric laminae of the cortices with the surrounding matrix is sharp and clear. The green laminae consist mainly of tangentially oriented flakes of green chamositic clay, intermixed with less abundant amorphous iron oxyhydroxides and dusty kaolinite (Pl. 4b, c). The hematitic laminae consist entirely of coalesced and tightly spaced tangentially oriented small-hematite crystallities.

Kaolinitic Ooids

Kaolinitic ooids are commonly observed within the middle part of the small-scale coarsening-upward cycles and are often associated with the hematitic ooids (Fig. 2). Less frequent kaolinitic ooids are also observed within the uppermost oolitic sandy ironstone beds. Most of these ooids are uncored and consist of thin 5 to 10 μm, concentric kaolinitic laminae intertounged with and/or laterally changed into yellowish green chamositic clay and/or hematitic and hematitic-kaolinitic shreds (Pl. 4d). Kaolinite shows randomly oriented and tightly coalesced floccules intermixed with less abundant blotches and dots of amorphous iron oxyhydroxides giving

PLATE 4

a) Chamositic ooid consisting of intra-sedimentary accreted ooidal core and enveloped by extra-sedimentary (mechanically) accreted laminae (P.S., O.L.)

b) Chamositic (ch)and hematitic (h) laminae of the chamositic ooid of Fig. a, the chamositic laminae contain relicts of precursor kaolinitec (K); P.S., O.L.

c) Chamositic laminae (ch) of the chamositic ooids obscured by authigenic kaolinite (k), T.S., O.L.

d) Kaolinitic ooid consisting of intertounged and laterally changed laminae of kaolinite (k), green chamositic clays (ch) , hematite (h) and amorphous iron pxyhydroxides, T.S, O.L.

e) Rounded kaolinitic-hematitic ooids with concentric continuous and discontinuous hematitic (h) and kaolinitic (k)zones and laminae, T.S., O.L..

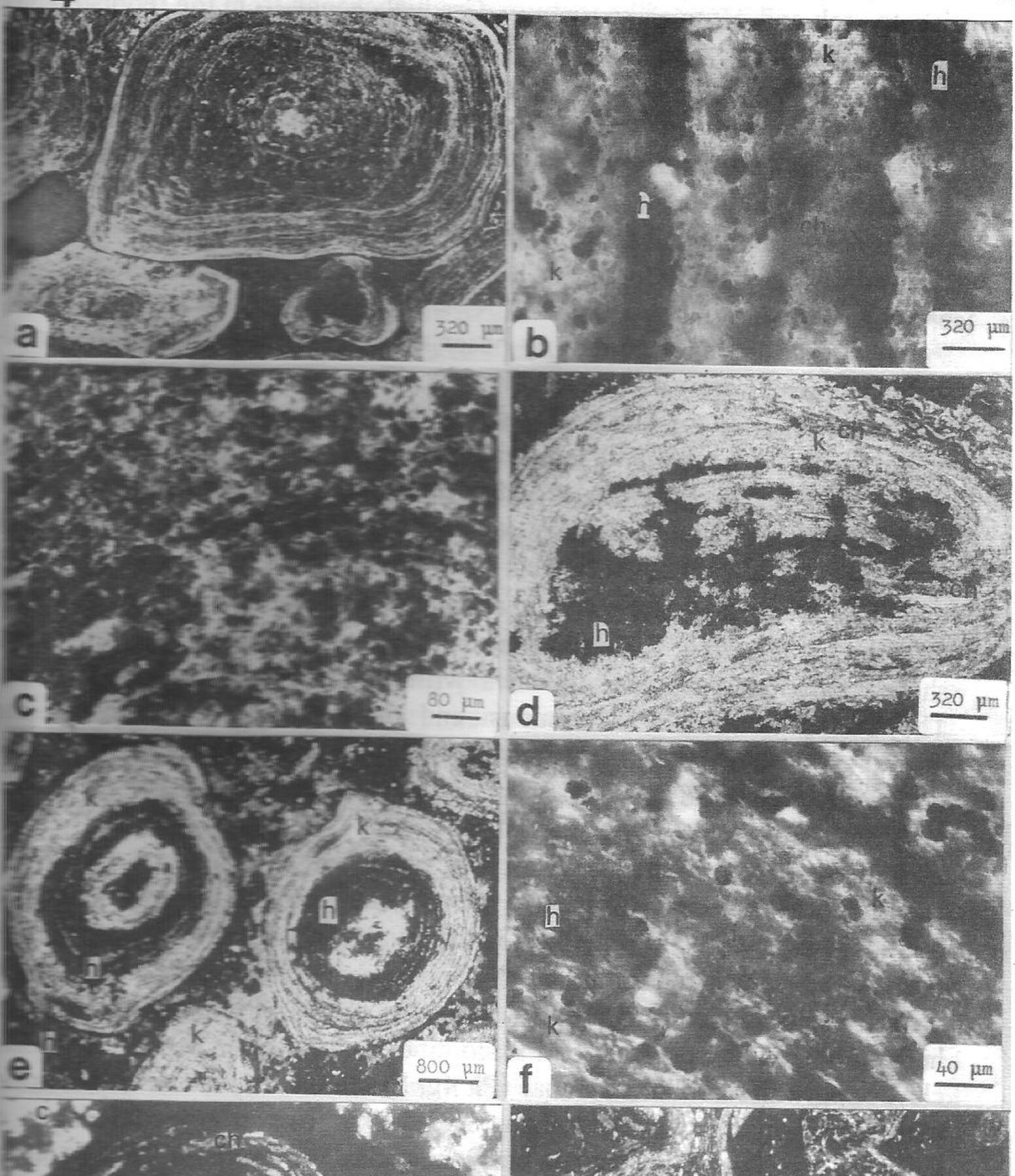
f) Irregular and gradational contacts between the hematitic and kaolinitic zones and laminae of the kaolinitic-hematitic ooids, k=tangentially arranged kaolinite flocules, h=hematite, i-amorphous iron oxyhydroxides. (T.S., C.N.)

g) Rounded concentric hematitic ooid with central zone of green chamositic clay (ch); h=hematite, c=calcite; (T.S., C.N.)

h) Pure hematitic ooids of rhythmic alternating and laterally intertounged kaolinitic (k), hematitic (h) and iron oxyhydroxides (I) zones and laminae (T.S., O.L.).

T.S. = Thin Section
P.S. = Polished Section
O.L. = Ordinary Light
C.N. = Crossed Nicols

Plate 4


a
320 µm
b
k
h
ch
320 µm
c
80 µm
d
k
ch
h
320 µm
e
k
h
800 µm
f
h
k
40 µm
g
c
ch
h
320 µm
h
k
80 µm

rise to salt and pepper-like texture. Gradual change from the reddish white hematitic-kaolinitic laminae into lighter kaolinitic ones are not uncommon. In certain domains, the proportion of the dark hematite crystallites increase relative to the white kaolinite floccules and dark hematitic aggregates and micronodules predominate. These aggregates and micronodules show replasive boundaries against the surrounding kaolinitic laminae.

Kaolinitic-Hematitic Ooids

These ooids are commonly observed in the middle parts of the small-scale coarsening-upward cycles (Fig. 2). They are generally of small cores and consist of concentric continuous and discontinuous dark hematitic and white kaolinitic zones and laminae (Pl. 4e). The light kaolinitic zones are composed of thin continuous and/or discontinuous white kaolinitic and/or yellowish green chamositic clay laminae. The kaolinitic laminae consist of randomly to tangentially oriented ultra-fine kaolinite floccules and flakes with less frequent short euhedral authigenic kaolinite crystals, up to 40 µm in diameter. The dark hematitic zones and laminae, 80 to 100 µ in thickness, show gradational irregular contacts with the associated kaolinitic zones. They consist of thin continuous and discontinuous hematitic laminae including smaller discontinuous white kaolinitic and/or yellowish green chamositic clay shreds (Pl. 4f).

Hematitic Ooids

These ooids comprise the main framework components of the true oolitic ironstone beds (Fig. 2). Generally, they do not show a well defined delicate concentric structure as that observed in the other ooid types and consist entirely of dark brown to black continuous and discontinuous hematitic zones, separated by discontinuous yellowish green chamositic clays and white kaolinite laminae (Pl. 4g, h). Internally, the hematitic zones consist of rhythmically alternating and laterally intertounged laminae of hematite with or without green chamositic clay and kaolinite. The kaolinite floccules and the hematite crystallites show some signs of tangential arrangement while the green chamositic clays are of patchy nature and do not show any signs of arrangement. This indicates the formation of these green chamositic clays during the subsequent diagenetic processes from precursor fine-grained kaolinite and hematite. (El Sharkawi *et al.*, 1996 b).

DISCUSSION AND CONCLUSION

1) Aswan oolitic ironstones are confined to the shallow marine succession of the Coniacian-Santonian Timsah Formation. Their stratigraphic setting and sedimentological aspects reflect deposition in agitated condition along bar flanks and bar crests during regressive events terminating short-lived small scale prograding regimes. Each shoaling cycle starts with ferruginous mudstones which grade upwardly into ooidal wacke-and pack-ironstones. Ooidal grain-ironstone and ooidal sandy grain-ironstone terminate each cycle.

2) There is an obvious upward increase in the ooid generation within each shoaling sequence, passing from peloids and proto-ooids in the basal part into normal and composite ooids along the upper parts. There is also an obvious upward variation in the mineralogical composition of the ooids.

3) The external and internal morphology of the ooids indicate that oolitization had been taking place by intra- and/or extra-sedimentary accretion, and reflect a clear variation in the rate of supply of the land-derived fine constituents, in the strength and direction of currents and in the physico-chemical conditions that prevailed during oolitization.

4) The concentric ooids are suggested to be formed by mechanical accretion of nuclei which were free on the sediment surface during the time of accretion. The predominant polar accretion and also the slight shift in the equatorial plane of these concentric ooids suggest formation during stationary accretion. Thus, the mechanical accretion of the concentric ooids had been achieved during alternating periods of free motion and stationary states of nuclei. Accretion during free motion of nuclei or precursor ooids seems to be dominated during periods of low rate of supply of fine constituents and strong currents. during these periods, the inputted materials (ultra-fine kaolinite floccules, hematite crystallites and amorphous iron oxyhydroxides are kept in suspension long enough to permit a tangential accretion pattern (Markun and Randazzo, 1980) and kaolinitic, kaolinitic-hematitic and hematitic ooids were formed.

5) Accretion during higher rates of supply and weaker currents led to the predominance of stationary periods and also rapid accretion of

randomly arranged constituents. During the stationary periods of ooids along the sediment-water interface, the deposited fine constituents were partially to completely chamositized and then accreted in association with suspended constituents during the next agitation period. The alternation between the agitation and stationary accretion periods resulted in the development of concentric and eccentric ooids.

6) The mineralogy and internal geometric evolution of the eccentric ooids suggest their formation during deposition of fine constituents on partially buried nuclei or ooids by unidirectional water currents.

7) Reworking of already formed ooids and their redeposition are indicated by the development of ooids by different modes of accretion, and the presence of some ooids cored by half-moon ooid fragments. Most of the fragmentary ooids, however, have probably formed through the rolling and inveitable collision of desiccation-cracked ooids, under the influence of weaker currents. The development of desiccation cracks was probably caused by occasional subaerial exposure of grains in the depositional environment, and /or through diagenentic proccesses of dewatering immediately below the sediment-water interface. The presence of composite ooids reveal the progressive rolling and addition of accretionary laminae on the already formed ooids.

8) The occurrence of superficial ooids cored by large mudstone and siltstone fragments, as well as the occurrence of small microunconformities within some ooids, may reflect an intermittent periods of accretion and ooids formation, exposuring and reworking. This is supported by the presence of ooids showing evidence of formation during intra-and extra-sedimentary accretions. The exposuring periods are also evidenced by the presence of some ooids showing development during multistages of accretion where concentric ooids are usually cored by small eccentric ones.

9) Plastic deformation during compaction and formation of spastoliths, reworking and diagenetic recrystallization led to the obliteration of the original ooid fabrics and modifications in their mineralogical compositions. Fracturing of the ooids and development of syneresis cracks responded to a spontaneous dewatering.

10) The abundance and distribution of the observed mineralogical phases and their occurrence in zones and laminae can be related to the

proportion and composition of the inputted precursor fine detrital constituents as well as the variation in the physico-chemical conditions that prevailed during the progressive steps of ooid formation and diagenesis, i.e. chamositization and hematitization.

11) Discontinuous green chamositic clays are only observed in the laminae containing kaolinitic floccules and hematite crystallites in somehow equiproportion. El Sharkawi *et al* . (1996b) concluded that the chamosite of Aswan ironstones was constructed through the destruction and dissolution of the detrital kaolinite and addition of the resulted Si and Al to Fe^{2-} (derived from the precursor amorphous iron oxyhydroxides and hematite crystallites) and Mg (derived from the medium). This reaction rook place in a reducing environment which prevailed along the sediment/water interface as well as below the sediment surface, prior and during oolitization and before subsequent diagenetic processes.

Kaolinitzation led to the formation of authigenic vermicular kaolinite individuals during recrystallization of fine grained allogenic kaolinitic clay laminae and matrix. Formation of some of the authigenic kaolinite crystals by direct crystallization from silica and aluminum rich solutions is evidenced by the occurrence of euhedral crystals filling pore spaces. There is a general agreement for the formation of authigenic kaolinite by meteoric water with a low salinity and a positive Eh (Bucke and Mankin, 1971, McBride, 1987 and Pettijohn *et al.*, 1987).

Recrystallization of the detrital hematite dust into fine crystal aggregates and nodules and the hematite coatings around clay domains and filling of drying out features represent subsequent diagenetic leaching, redistribution and recrystallization of hematite during dewatering processes. The derivation of hematite and/or geothite by diagenetic dehydration of precursor iron oxyhydroxides or ferrihydrite is currently postulated by Van Houten (1972), Schwertmann and Murad (1983) and Gehring (1989). Alteration of green chamositic clays into hematite and formation of hematite pseudomorphs argue that chamositic clays represent a precursor source of diagenetic hematite.

Silicification led to the formation of authigenic quartz in the ooid cores, cortices as well as in the matrix. Pore filling crystals showing idiomorphic termination towards the empty spaces are also recorded.

Late calcite forms mosaic crystals filling the remained spaces left behind the framework components and hematite and quartz cements. Some ooids and other framework constituents are partially to completely replaced and embayed by the calcite cement.

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تطور التركيب المعدنى و الانسجة الصخرية اثناء و بعد عمليات الترسيب للصخور الحديدية البطروخية الكريتاوية باسوان – مصر

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تتواجد الصخور الحديدية البطروخية مكتنفه داخل الوحدات المتوسطة المنظومة الرملية للتتابعات الترسبية لمكون التمساح و التى تمثل ترسيب على جوانب حواجز رملية او بطروخية شاطئية في بيئة ضحلة و عكرة و من رواسب اولية منقولة.

امكن تمييز ثلاث انواع من الطبقات الحديدية داخل الصخور الحديدية البطروخية تمثل دورةصغيرة لانخفاض مستوى سطح البحر و هى من اسفل الى اعلى حجر صينى شاموزيتى يعلوه حجر صخرى حديدى بطروخى فقير ثم صخر حديدى بطروخى يتكون اساسا من سرئيات حديدية.

و قد دل التشريح الداخلى و التركيب المعدنى للسرئيات المكونة للرواسب الحديدية البطروخية على تجمعها من مكونات اولية لاتيرتية المنشأ و بفعل الدحرجة على الحواجز الرملية او البطروخية الشاطئية اثناء تراجع البحر و امكن تمييز السرئيات الاتية :

اولا : سرئيات تكونت فى مكانها تحت مستوى سطح التلامس بين الرسوبيات و مياه البحر بفعل عمليات ما بعد الترسيب.

ثانيا : سرئيات تكونت على سطح التلامس بين الرسوبيات و مياه البحر بفعل تجمع المواد الاولية المنقولة اثناء دحرجة السرئيات او ثباتها على جانبى الحواجز الرملية.

ثالثا : سرئيات تكونت نتيجة انتقال سرئيات النوع الاول ودحرجتها على جانبى الحواجز الرملية مع ترسيب مواد لاتيريتية اولية اثناء الدحرجة.

هذا و قد اثر التغيير فى نسبة توافر المكونات الاولية اللاتيريتية و التغير البيئى من شدة تيار و نسبة تعكر اثناء الترسيب ،و كذلك حجم و شكل انوية السرئيات اثر بشكل مباشر على التركيب المعدنى و الشكل الخارجى و التشريح الداخلى لهذه السرئيات.

اما عمليات ما بعد الترسيب و التى اثرت على هذه السرئيات فتمثل فى عمليات الدمـوج بفقد المياة الداخلية و تكوين معدن الشاموزيت ،و الكاولينيت و الهيماتيت ،و السلكيتة و اللحم بالكالسيت.